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ABSTRACT. The term "cosmic dust" is defined, the finding of cosmic dust on earth and in our system is discussed, and the basis for calculating the quantity of cosmic dust falling on earth used by various authors is presented.

Cosmic material will be understood to mean exogenous material, that is, /439* material originating outside the earth, in our solar-planetary system. This material includes cosmic dust, that is, dust originating from the decomposition of asteroids and comets, including dust from the zodiacal light, and meteor dust originating from disintegration of meteoliths[1] in our atmosphere, as well as meteorite dust from the impact of meteorites falling on the earth, or from the dusty residues after passages of large cosmoliths through our atmosphere.

We know that our system contains many thousands of different sized bodies and lumps (which I call cosmoliths) that fall upon the earth in the form of meteorites as they move about. Collisions between them, and collisions with asteroids break these pieces into smaller and smaller lumps, which finally become dust. Collisions between asteroids have the same results. This process is called the "cosmic grinder." It also is fed with material from the zodiacal light, the extension of the sun's external corona and composed of minute grains of dust microns in magnitude and forming a ring, or a lenticular cloud, whose dust moves around the sun in spiral orbits. Some people estimate the mass of this cloud to be four billion times the mass of earth. To be sure, the earth is part of this medium, and captures part of its mass, but we shall not take this mass into consideration. This medium is unusually rarefied, and its dust is so fine that at an altitude of 120-150 km above the earth it loses its geocentric velocity completely, remaining suspended in the atmosphere for some period of time as it floats down slowly to the earth, unseen as meteors observable with the naked eye, or in any other way.

1. The name given to small bodies and lumps penetrating our atmosphere and producing the phenomenon of meteors.

* Numbers in the margin indicate pagination in the foreign text.

There also is an interstellar dust-gas "background." Its density, based on different theoretical solutions from observations, is approximately 10^{-26} g/cm^3, and dust grain size 10^{-5} cm. The earth certainly captures some of this dust, but because of the above-indicated enormous rarefaction of this material, it is difficult to include in our calculation [7, 11, 13].

Our solar-planetary environment also contains dust originating from the disintegration of comets, the quantity of which can be relatively large, based on the number of meteors of cometary origin and on the number of comets visiting our system. In 1967, for example, 14 comets were observed, 10 periodical and 4 new. Each of these comets leaves a certain amount of dust in circumsolar space, and of course many comets are unobserved.

Theoretically, as we have said, we can distinguish a few sources and kinds of exogenic dust, sometimes inaccurately called meteor dust in a general way; but the distinction of the genesis of the dust in practice after it reaches the earth is extremely difficult, if not impossible.

Exogenic dust collected on earth is of the order of magnitude of microns. Dust found by Nininger in 1940 measured ± 90 microns. Buddhue [4] found that dust collected in different ways (from rain, snow, hail, and so on) either was spherical, 0.005-0.2 mm in diameter, or angular, and was composed of glass, magnetite, and metal (Fe 7-11% and traces of Ni).

Wiiding [28] has some interesting findings about "fossil" cosmic dust (which has been found). It was found in Lower Cambrian clayey sands in a shaft at 374.4 m. The author further says the compaction of this material was greater than 5 kg/m^2. This great concentration can be explained, supposedly, by the explosion and pulverization of some gigantic cosmolith, or by sedimentation of dust over /440
a very long period by comparatively steady surface evaporation in a more or less normal background of cosmic material.

Duty bound, we quoted the above findings by Wiiding, but we have serious doubts as to the accuracy of the concentration cited.

In Poland, a curious scientific achievement was the discovery of cosmic dust by Tadeusz Wieser in deposits along the Carpathian geosyncline between Jura and Neogene. This dust, equally metallic and stony, was an average 70 microns in size [25]. This interesting work is worthy of attention, both as the first discovery of this type in Poland, and because of its curious content.

In 1870, Nordenskiöld, the well-known polar explorer, found a grayish deposit he called krokonite (ice dust) on the ice in Greenland and hypothecated it to be cosmic dust. Subsequent investigations failed to confirm this hypothesis, however.

The first authentic cosmic dust was found a few years later (1876) in samples of deep ocean sediments by John Merreé during the oceanographic expedition of the Challenger [2]. Later expeditions, such as the Swedish expeditions in Galatea and Albatros continued the earlier explorations. The harvest by Albatros between 1947-1948 was particularly rich. Its equipment took small "core" samples of bottom deposits from a depth of over 5.5 m, that is, from levels dating back many millions of years. Thousands of nodules of magnetite and silicate were found. Nodules collected by Merreé, and examined at the Stockholm Mineralogical Institute, showed their composition to be mostly of nickel iron in the same FeNi proportion as occurs in iron meteorites [6, 21].

The collection of cosmic and meteorite dust from earth's surface is rather complicated because, among other things, of the impurities in the atmosphere put there by industry, volcanos, and lately by nuclear explosions.

Fjesjenkow cites several instances of detection of cosmic dust, but what strikes me about them is the nickel-free metal composition of some nodules supposedly of cosmic origin [5]. The phenomenon requires explanation.

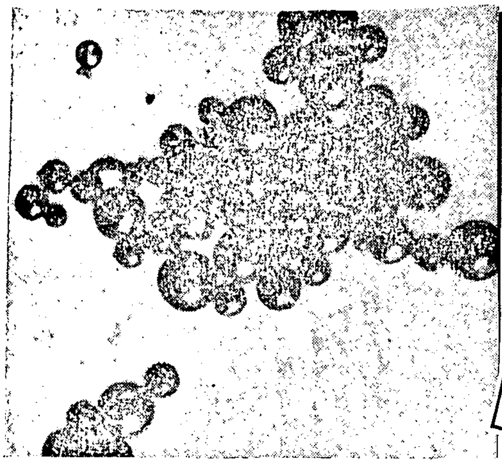
Generally, disintegration of cosmic dust on the earth's surface is rather uniform, but this uniformity can be disturbed locally by the fall of a large cosmolith, which yields a great deal of dust.

Rocket traps, shot to high altitudes, have recently collected dust of extraterrestrial origin. A 1961 rocket launch by the USA trapped 133 extraterrestrial particles, the majority of which were 0.1-1 micron, and only 11 were larger than 1 micron, at altitudes of 116-168 km in 4 minutes. Three particles 30,100, and 150 microns in diameter, which had speeds of 2 km/sec, were found.

Artificial earth satellites also have been used to examine cosmic dust. The procedure was to record the number of impacts of the dust particles with special equipment installed in the satellites. The number of impacts recorded by three Soviet satellites on 15 May 1958, for example, ranged from 4 to 11 1 m^2, but quickly dropped within a few days. It is supposed that on 15 May the earth encountered a stream of "meteors" (the Akwaryd shower is active in May). It is highly likely at this time that no dust of terrestrial origin will be found above 50 to 60 km from the earth, although it often is impossible to distinguish cosmic dust from industrial dust with adequate certainty when examining the dust found on the earth's surface [27].

Meteor dust also was sought (and supposedly found), after the 10 October 1933, Draconid (Rudaux) shower, and after the Orionid shower on 19-20 October 1947, 700 dust particles, about 700 microns in diameter, were collected [4]. Ordinary rain which fell on Ghent (Belgium) on 28 November 1885, and the heavy andromedid meteor shower of the next day, were analyzed by Young, who found meteoric particles. In pondering these bits of information, we cannot help noting the apparent error in linking the dust finds with specific meteor showers the next day because meteoric dust does not fall immediately after the disintegration of meteors, but later, after some longer period of time. Dust floated in the upper layers of the atmosphere for at least two months after the fall of Tunguska cosmolith, for example [5].

In general, fallout of dust connected with the fall of large meteorites /441 has been observed many times. Black dust was observed on the snow on the Narew River [18] after the fall of the Pultusk meteorite. Dust-like material (globules) was found around the Arizona crater and after the fall of the Sikhote-Alin! meteorite. The globules collected around the Arizona crater with an area of 160 m^2 in the proportion of 100 g per 30 cm^3 of terrain contained 17% Ni, considerably more than that contained by the Arizona meteorite (octaedrite: (Om) Ni 8.42 or (Og) Ni 7.33). Moreover, they showed cohenite, schreibersite, and troilite. Nininger supposed these globules could form from the condensation of methane gases released by the explosion of the cosmolith [16]. Krinow and Fonton criticize this hypothesis, and think that these globules simply are oxidized nuclei of fine meteorites [8]. Still smaller globules, 0.1 - 0.01 mm in size, were extracted by a magnesium needle from the ground at the back part of the ellipse of the Sikhote-Alin! meteorite. It is supposed that they originated from the process of the blowing away of the minute droplets from the melting surface of the meteorite flying through the atmosphere.



Magnetite globules originating from material of the dust trace of the Sikhote-Alin' meteorite (Sikhote-Alin' Iron Meteorite Rain, Vol. 1, Moscow, 1959, p. 116).

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Meteoric, and in part meteorite, dust falls on the earth very freely, and is dispersed by atmospheric currents at speeds of 300 km/hr. The prevailing speeds are at altitudes of 80 to 120 km for the most part. If the size of the dust particles is of the order of magnitude of tens of microns, their fall can last for several months, and if they are of the order of magnitude of 1 micron, it can last for several years. Budhue, in his fine work on cosmic dust [4], provides a table showing rates of fall of dust particles in terms of altitude size.

After this somewhat lengthy introduction, the purpose of which is to provide a general explanation of what this cosmic material is whose mass falls on the earth we are about to discuss, I come to the topic of my work, the question of the mass of extraterrestrial, so-called cosmic, material that falls on the earth.

Different authors will use particular materials on the subject and will arrive at different conclusions. According to the calculation of several authors, the total mass of the "micrometeorite" material, that is, of the dusty material, that falls on the earth exceeds the mass of the falls of meteorites and "meteors" by a factor of 1000-10000. This would mean that the daily fall of meteorites would be less than 1 ton, that of the disintegration of "meteors" and bodies would be from 1 to 10 tons, and that of "micrometeorites"[2] would be from 1000 to 10000, for an average of 6000 tons per day [26, 19, 14].

2. Whipple [24] gave this name to cosmic dust. Krinow rightly criticizes it by saying that only real, wholly microscopic meteorites deserve this designation; that is, those found after the fall of the Sikhote-Alin' meteor. Their sizes were 1.51 x 0.94 mm, weight 0.0058 g, 0.83 x 0.49 mm, weight 0.0021 g, and 0.83 x 0.49 mm wight 0.0003 g [10]. Krinow showed this under the microscope during my stay in Moscow for the Meteorites Conference in 1956. Actually, except for size, they are no different morphology from large meteorites.

The calculation of the quantity of cosmic dust falling on the earth is based on a general consideration of the density of dust in interstellar space, and (in particular) on the quantities of dust actually collected, as well as on the number of meteors observed visually, and by radar. Included in these calculations was the Ni found in the bottom deposits of water basins, and the results of measurements made of dust in the atmosphere by artificial earth satellites and rockets [22].

If we rely, for example, on the work by Petterson and Rotschi [17] con- /442
cerning nickel in the bottom deposits of ocean basins, we obtain an annual fall of cosmic materials on the earth of 1.4 million tons annually, or about 4,000 tons daily. Petterson also collected dust on high peaks on Mauna Loa and Haleakala in Hawaii, where the atmosphere contains no admixtures of dust of terrestrial origin. The total content of "meteoric" dust in the atmosphere is estimated to be 28.6 million tons. If we assume that the rate of fall of this dust is the same as that of the dust fall after volcanic eruptions (Krakatau volcano for example), it can be shown that the increment of the mass of the earth attributable to this dust is 14.3 million tons annually, and that is almost 40,000 tons per day [1, 15]. It should be noted that "Petterson's dust" contained considerable quantities of iron and nickel, and this could have had an influence on their weight. Regardless, Petterson's figures are many times those found by other authors, and this shakes the reliability of his premise.

As to the number of meteorites falling on the earth, Brown [3, 12a] for example, estimated the number to be some 500 annually, relying on the number of meteorite falls observed during the last century in Japan, India, and Western Europe. Krinow, on the other hand, raised this number to 1000 [9]. Watson [23] used the 25 meteorites falling annually in the central part of the USA to estimate the fall for the earth as a whole at 2,000 annually, or 5 or 6 a day. This latter number seems possible, although the premises upon which it is based are in doubt because not a single meteorite fell on the territory of the USA between 1961 and 1967.

Certainly, these calculations are relative, at least from the standpoint of the mass of meteorite falls. One fall is not equal to another. Some are of the order of kilograms, or grams, while others (the Sikhote-Alin', or the

Norton County) are of the order of tons. In any case, the mass is supposedly insignificant, constituting, as I have pointed out, an average one ton per day.

Different authors use different methods to try to estimate the quantity of cosmic material that falls on the earth. W. Tomson has estimated it to be from 1×10^6 tons to 3.7×10^6 tons annually. P. Hodge and R. Wildt have estimated it to be 0.5×10^6 tons, F. Link 80×10^6 tons annually (see Wieser [25]), and W. D. Grozier 13×10^6 tons annually [27]. Some estimates are much lower; Whipple says 7×10^5 tons per year. Others are still lower; C. C. Wylie, Watson and Schwinner [27], but their papers go back to 1935-1936.

Finally, Dr. J. W. Morgan, of the Australian Atomic Energy Commission, turned his attention to the special chemical composition of shales in the Silurian rocks of the Australian Capital Territory. They contain 8.7 atoms of osmium for each atom of rhenium, unlike the usual rocks of the earth's crust (crustal rocks) in which the rare elements are mentioned in a more or less identical proportion to each other. Since the results of recent analyses of 32 chondrites from observed falls show the ratio of osmium to rhenium in them to be 11.4, the supposition is that the above shales were enriched by extraterrestrial chondrite material. Assuming this hypothesis to be true, further considerations by this author lead to the conclusion that the quantity of extraterrestrial material falling on the earth amounts to 8,000 tons daily, that is, a quantity of the same order of magnitude as the findings of some of the above authors [20].

If we reject the extremes it seems that an average 6,000 tons daily for the fall of exogenic material will not be an overestimation, and may even be lower, as some recent data seem to indicate [1].

Is 6,000 tons too much or too little? At first glance it seem too much, but in proportion to the earth's mass is a negligible amount. Indeed, the mass of earth is 5.974×10^{27} g, including 7% water in all its forms, so a surface which, in round figures, is 500 million km^2, would increase its mass from extraterrestrial sources by not much more than 10 g per day per km^2, or 1/100,000 g per m^2 daily; in other words, 1 g per m^2 over 275 years [26].

Has man sometimes been a witness to the fall of clouds of cosmic dust? Have there been phenomena that make possible the witnessing of such falls?

Historical data on similar phenomena are found in the literature [2, 12]. Still, caution is recommended in ascribing a cosmic genesis to such phenomena. Undoubtedly, the majority of these phenomena, and perhaps even all of them (I disregard here the phenomena which occured after the passage of the Tunguska cosmolith), were produced by dust of terrestrial origin.

Let me conclude by citing a recent report. Data obtained by piezometric traps used by the American National Aeronautics and Space Administration (NASA) for its Alfa and Eta satellites resulted in the determination that the quantity of cosmic dust that infiltrates the closest neighborhood of the earth is 10,000 tons daily (3,650,000 tons annually) [29]. /443

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